THE SYSSON PLATFORM: A COMPUTER MUSIC PERSPECTIVE OF SONIFICATION

Hanns Holger Rutz *Katharina Vogt* *Robert Höldrich*

University of Music and Performing Arts Graz
Institute of Electronic Music and Acoustics (IEM)
Inffeldgasse 10, 8010 Graz, Austria
`rutz | vogt | hoeldrich @iem.at`

ABSTRACT

We introduce *SysSon*, a platform for the development and application of sonification. *SysSon* aims to be an integrative system that serves different types of users, from domain scientists to sonification researchers to composers and sound artists. It therefore has an open nature capable of addressing different usage scenarios. We have used *SysSon* both in workshops with climatologists and sonification researchers and as the engine to run a real-time sound installation based on climate data. The paper outlines the architecture and design decisions made, showing how a sonification system can be conceived as a collection of specialised abstractions that sit atop a general computer music environment. We report on our experience with *SysSon* so far and make suggestions about future improvements.

1. INTRODUCTION

The *SysSon* platform has been developed for the past two years as part of the eponymous research project [1] funded by the Austrian Science Fund (FWF), P 24159. It is an open source software[1] that provides both an application programming interface (API) and a standalone desktop application. Fig. 1 is a schematic view of its components and the types of users and activities it supports.

The current design is the result of an incremental refactoring that departed from the initial requirements of the research project, namely to be able to open and preprocess data files to become suitable for real-time sound synthesis based on *ScalaCollider*, a client for the *SuperCollider* server [2].

Another objective was to enable climatologists to integrate sonification with their typical workflows. Originally coupling to existing plotting software such as *Ncview* and building a simple domain specific language (DSL) for text-based interaction, the platform gradually acquired the shape of a full-fledged desktop application.

As the system became more complex, new requirements for higher-level resource management, caching, and a persistent description of sonification models emerged, and we repositioned the project on the foundation of *Sound Processes*, a computer music framework [3]. The platform was fully "infected" by the dataflow model of this framework, and the specific abstractions used for sonification were reimplemented within the object model of *Sound Processes*.

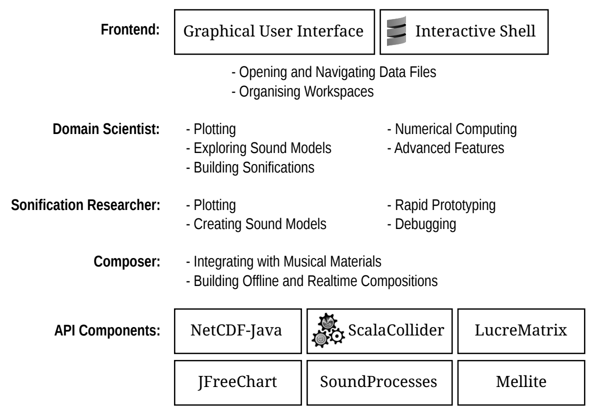

Figure 1: SysSon architecture

This shift was reinforced by the planning of a sound installation, where sonifications would be interactively composed. Consequently, as a last step, the GUI was integrated with the computer music front-end *Mellite*. What we arrived at is a perspective in which sonification becomes a particular methodology of computer music. What we hope for is that, as composers get acquainted with *Mellite*, they will discover and explore the possibility of sonified data as a new material element in their work. Of course, many composers and sound artists have utilised sonification processes (e.g. [4], [5], [6]), but there exists no general platform for the systematic experimentation with sonification that equally satisfies the needs of researchers and artists and lets them directly share their ideas.

In the following, we give an overview of our system. It is still a young project and not without obstacles, and we will conclude by summarising the experience with its usage so far.

2. HOST ENVIRONMENT

Sound Processes is a frameork that is the result of research into the observation of the compositional process. It provides data structures that trace the evolution of computer based composition over time, making these traces available for later inspection or for incorporation into the process itself. But it can also be transparently used as a foundation to build computer music systems.

[1] `https://github.com/iem-projects/sysson`

2.1. Common Objects

Sound Processes provides two core functionalities. First of all, it defines a protocol for reactive (data-flow like) objects, and it contains a number of useful objects, such as:

- atomic types: integer and floating point numbers, boolean expressions, strings, . . .
- folders: they are containers for other objects and similar to a sub-patcher in *Max* or *Open Music*.
- artifacts and artifact locations: artifacts are logical references to external file resources. Artifacts are resolved through locations, and when a workspace is transported to a different computer, locations can be adjusted to resynchronise with external resources.
- audio-files: they are a specific type of artifact.
- proc (or sound process): a description of a sounding object. It encapsulates a DSP graph in the *ScalaCollider* language, which is a dialect of *SuperCollider*. It also contains ports (called scans) to connect to other processes.

The object protocol is extensible, and *SysSon* uses it to add its sonification abstractions.

The second functionality is sound synthesis. Model objects, such as an audio-file, a proc, an ensemble (group of objects) or a timeline may have corresponding *aural representations*. *Sound Processes* integrates a transactional memory model with the sound synthesis system and provides high level abstractions for dealing with graph topology and resources such as audio-buses and buffers.

2.2. Workspace

Mellite provides a graphical user interface for *Sound Processes* and defines the workspace as the basic organisational unit. A workspace in most cases is simply a root folder that can be thought of as the main "patcher". The creation and modification of objects inside this patcher are automatically synchronised with an underlying database. We thus ensure that the user can come back to the workspace at any later point and will find everything in its previous state, including for example the parametrisation of sonification models or plot objects. To preserve state, one can either duplicate objects or use an automatically versioned workspace that traces the evolution of all parameters over time.

The GUI uses metaphors of a standard desktop application such as point-and-click, drag-and-drop, and undo-redo. Fig. 2 shows an example workspace containing two locations, a folder with data-sources, a folder with sonification models, an audio-file and a plot. Except for locations and audio-file, these are objects introduced by the *SysSon* platform.

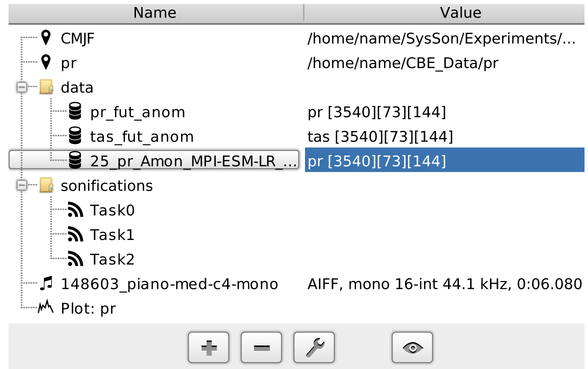

Figure 2: Workspace view

3. SYSSON ABSTRACTIONS

We now describe the main abstractions provided by *SysSon*.

3.1. Data-Sources

Data sets for sonification can become very large, and domain sciences have come up with file formats to store them. *SysSon* supports *NetCDF* (Network Common Data Form) [7], a format frequently used in atmospheric research. *NetCDF* files can easily grow to several hundreds of megabytes, and they are therefore not copied but merely linked to workspaces as external references through handles called data-sources.

When a data-source object is created, its skeleton structure consisting of a number of variable descriptors (matrices) is stored with the workspace, allowing to operate even when the underlying *NetCDF* file is offline. A data-source is associated with an artifact which can be updated when a workspace is moved to a different computer.

Adding different types of data-sources in a future version should be simple. For example, at the moment a *CSV* file would have to be converted to a *NetCDF* or audio-file first, but there is no reason one could not add direct support.

3.2. Matrix Structure

A matrix is a regular one- or multi-dimensional structure of floating point cells. Dimensions are simply represented by other matrices. For example, a matrix of precipitation data may have dimensions *lon* (longitudes), *lat* (latitudes), *time* (time-series). Each of these dimensions then is another one-dimensional matrix (or vector) that stores the dimension's values, such as the series of latitudes with unit 'degrees-north'.

Matrices are composed and transformed through a data-flow graph. They usually originate from a data-source object. To be editable in the user interface, a variable placeholder is used that stores the current data-flow graph. Transformations then become new nodes in this graph. The most common transformation is a reduction of the matrix's size using a reduce object. The reduce object takes an input matrix, a dimension-selector and a reduction-operator. For example, to produce a time slice of the aforementioned precipitation matrix, the dimension-selector would indicate the time dimension and the reduction-operator is an index into the time dimension. The output matrix thus has a rank of one less than the input matrix. Each of the objects related to the reduction is again made editable through data-flow variables holding the dimension's name and the index integer position. This is illustrated in Fig. 3, where the resulting matrix expression at the very bottom could be a parameter of a sonification model.

Other operators take slices (ranges) of a dimension or perform sub-sampling by skipping samples using a stride parameter. Future versions shall include other commonly used operators such as dimensional reduction through scanning and sub-sampling using

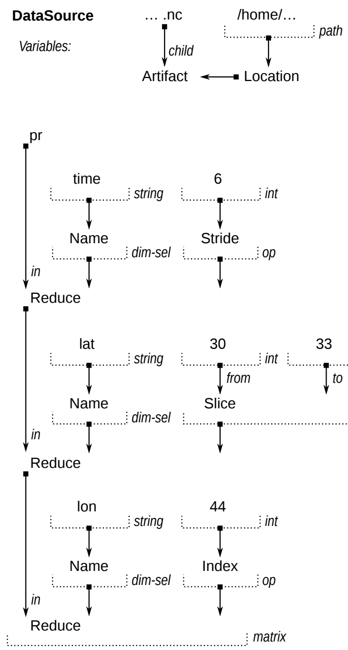

Figure 3: Composed matrix graph. Dotted trays represent variable (mutable) data-flow cells.

averaging or interpolation, as well as binary operations such as taking the element-wise differences between two matrices. Currently, those operations can only be carried out eagerly, producing new matrix files.

3.3. Plot Objects

Plot objects encompass a matrix, a mapping from dimensions to axes, and visual parameters such as colour palette and scaling. Fig. 4 shows an example plot of a time slice of precipitation data.

3.4. Sonification Objects

Sonification instances are encapsulated by a dedicated object type. This object is composed of

- a proc (sound process) object that describes the sound production in terms of a synthesis function.
- a dictionary of sources where a logical name in the sonification model is associated with a tuple of a matrix and a dimensional dictionary. The dimensional dictionary provides logical dimensions for the sound model that may want to use them for unrolling the matrix in time or to drive specific sound aspects such as timbre or spatialisation.
- a dictionary of controls which are user adjustable scalar parameters of the sound model. For example, a typical control would be the speed at which a sonification traverses a time series.

The user interface for a sonification object is shown in Fig. 5. The section labeled ‘Mapping’ shows that the model uses a single

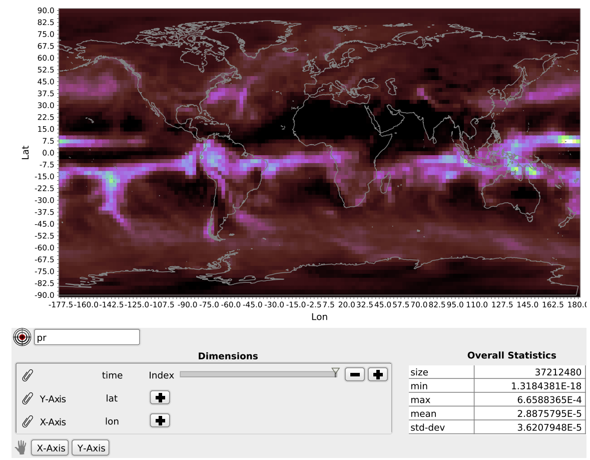

Figure 4: Plot view

source ‘data’ with which a matrix ‘pr‘ has been associated. This matrix has been reduced, the underlying graph corresponding with Fig. 3. The model also defines two logical dimensions ‘time‘ and ‘pan‘ which are associated with the matrix’s own ‘time‘ and ‘lat‘ dimensions. Using this dictionary-based decoupling, sonification models can be flexibly tested with different data inputs.

The sonification researcher or sound designer can open an integrated code editor within the workspace to develop the sound models. This is depicted in Fig. 6. Regular *ScalaCollider* expressions are augmented with user interface elements such as the ‘user-value’ object responsible for the ‘controls’ section of the sonification editor, and data specific elements such as matrix and dimension keys. Within the DSP graph, matrices and vectors may appear as scalar values or dynamic time-changing signals. When a sonification object is made audible, the system translates the matrix expressions into a cache of audio files which can then be streamed on the *SuperCollider* server. We exploit its multi-channel expansion feature and provide pseudo-UGens to easily align the matrix data with related data such as the axis dimensions.

4. EXPERIENCE

The platform has been used in multiple user tests, a workshop and for the creation of a sound installation.

4.1. As a Research Tool

Preliminary results show that both climatologists and computer music researchers had no problems navigating and configuring existing sonification models. During the workshop, it became clear that mastering the programming of sound models requires a longer learning process, as users need to gain an understanding of the nature of the data at hand, the architecture of *SysSon* and its model of data processing, as well as the sound synthesis language and the way it connects to the data inputs. The current focus on a graphical user interface without a direct equivalent in the interactive text console was seen as disadvantageous by some participants. Furthermore, experienced computer musicians felt the restriction of having one compound sound synthesis process limiting compared

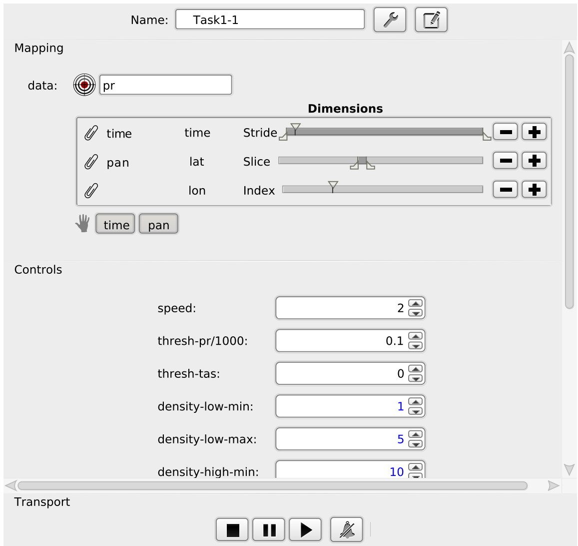

Figure 5: Sonification editor

to a more flexible client-side timing model provided for instance by *SuperCollider*'s pattern sequences.

4.2. Sound Installation

Using the platform in a real-time interactive sound installation was another stress test and rewarding experience. The piece *Turbulence. A climate sound portrait* was developed in collaboration with a group of visual artists for exhibition at the Forum Stadtpark, Graz in November 2014 [8]. The system is coupled to 42 speakers and 12 acceleration sensors that influence the selection of sound situations and the modulation of the exhibition space that is filled with a topography of threads and paper (see Fig. 7).

Embedding the sonification objects in a temporal form that changes according to compositional constraints and the signals of the sensors was an interesting challenge that especially led to the question of whether all structures should be composed inside *Mellite* or outside of it, using a conventional development environment. In favour of the former was the ability to directly evolve sound objects as the installation was running, in favour of the latter was the more mature editor and the ability to describe the interconnection of processes as text commands, something that is still cumbersome, as proc atoms must be instrumented with code fragments of actions that are triggered at points in time, revealing the limitations of the graphical user interface to represent relationships between the workspace objects.

In the end a hybrid approach was used to combine both advantages, where the layers of the composition were prototyped directly inside the environment but finally written back to regular class files. The seamless transition and interweaving in the sound composition from sonification based elements to purely musical macro form supported the perspective of sonification as one possible rendering among others in the repertoire of computer music.

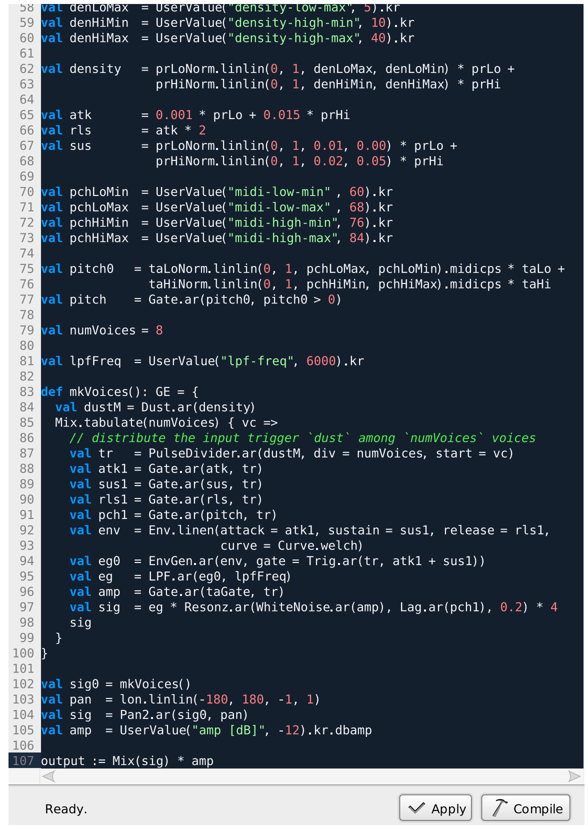

Figure 6: Synth Graph code editor

5. OUTLOOK

The future development of *Mellite* will have to focus on improving the possible oscillations between writing code fragments and connecting and arranging materials in the workspace, making this hybrid form more compelling to work with.

The *SysSon* platform will benefit from an expansion of the reactive matrix layer. Not only do we need more transformations—especially resampling—but ideally all matrix operations will be supported inside the definition of sound synthesis functions itself. For example, the sound designer should be capable of specifying a dimensional reduction of an input matrix or the calculation of anomalies, freeing the domain scientist from tedious preparations of the input data and yielding one unified API. Another iteration of the development could also focus on a more user-friendly DSL as a thin layer on top of the existing API to allow easier text-based access to the entire platform.

While *SysSon* has been validated within climate research, an interesting future task will be the application in other scientific areas. Here it will be seen if it can establish itself as a compelling alternative to other existing sonification solutions. From our perspective, its advantage over plain numerical computing environments such as *MATLAB* or *Octave* is the use of a well established sound synthesis system based on *SuperCollider* with a seamless transition to computer music paradigms and its potential for real-

Figure 7: View of the sound installation *Turbulence*

time control. More advanced numerical computing packages can be easily linked to the system, and the Scala language is establishing itself firmly in the "data science" community. The advantage over customised *Max/MSP* or *Pure Data* patches is the dynamic nature of the workspace, the sound models and the handling of data-sources (e.g. channel abstraction), something that is cumbersome if not impossible to achieve in static systems. Furthermore, we believe the dual perspective of visual front-end with desktop metaphors and the power of text-based API make our approach superior to patchers.

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THE SOUND OF THE PEDAL STROKE CYCLE: SONIFICATION OF THE WATTBIKE CYCLING ERGOMETER

Nina Schaffert

University of Hamburg,
Institute for Human Movement Science,
Hamburg, Germany
nina.schaffert@uni-hamburg.de

Andrew Godbout

University of Calgary,
Department of Computer Science,
Calgary, Alberta, Canada
agodbout@ucalgary.ca

ABSTRACT

The Wattbike is an air-brake cycling ergometer that provides pedal stroke information as visual feedback, allowing the user to adjust and correct their pedal stroke technique during training. This paper proposes that sonifying the pedal stroke data can provide another effective means of feedback about pedal stroke efficiency and introduces a system for sonifying data from the Wattbike. The goal is to provide acoustic feedback during cycling to make cyclists aware of their pedaling technique and to keep them concentrated on its correct execution.

We outline how it is possible to sonify the Wattbike pedal stroke and present a pilot study on early findings. Sonifying the Wattbike further opens the door for interesting analysis and comparisons of auditory and visual feedback.

1. INTRODUCTION

Cycling is a sporting activity that corresponds to a succession of periodically repeated motor sequences at relatively regular intervals. It is a popular activity not only for competitive cyclists, but also for recreational and health enthusiasts as well as for rehabilitation programmes. An issue therewith is individual cycling endurance performance, which is important to maximize efficiency. Research in cycling has identified and analyzed numerous factors that influence cycling performance (i.e. physiological, biomechanical, mechanical, and environmental factors) [1]. One factor was identified that contribute to efficiency is the pedaling technique (the way of the forces produced by the cyclist's muscles are transferred to the crank) [2].

Existing evidence is conflicting in terms of the relationship between performance in cycling and pedal force effectiveness [3]. Investigations in sports science suggest that improved pedal force effectiveness yields to reduced economy/efficiency (the ratio between mechanical energy produced and physiological energy demand) [4],[5]. However, according to Bini et al. [3], in the cyclist community, it is advocated that better force effectiveness can be translated to higher economy/efficiency [6]. Thus, cyclists still aim to improve pedaling technique by improving pedal force effectiveness. One way to develop this is to improve the coordination and synchronization of the muscles used in cycling. That can be accomplished by practicing correct pedaling technique. Good pedaling technique becomes even more important over long durations such as the 180 km Ironman ride. The forces applied to the pedals are commonly used to characterize pedaling technique.

1.1. Characterization of the pedal stroke cycle

The pedal stroke cycle is divided into a power and a recovery phase. Owing to the forces applied on the pedal, its circular motion is commonly viewed as a clock face in which the motion of cycling is simply broken down into four distinct parts, sectors, or quadrants: top dead center, power phase, bottom dead center and the recovery phase. It is important to notice, that during each sector, different muscles work and that a tradeoff happens between these muscles as the pedals are turned.

The first sector, the downstroke (also power phase), begins as the foot and pedal move from 0 to 180 degrees (12 o'clock to 6 o'clock), with the more propulsive section between 45 and 135 degrees (or generally the down-tube to about 5 o'clock). The backstroke (also follow-through phase) is the sector immediately following the downstroke in which the transition from the downstroke ends on one side and begins on the other. The backstroke overlaps with the downstroke and the third sector, the upstroke (also pulling phase), and is characterized by pulling backward and upward from approximately 120 to 220 degrees (4 to 8 o'clock). While in this sector, the opposite foot and pedal are entering the downstroke. The emphasis during the upstroke is on pulling upward from 270 to 360 degrees. The overstroke as the fourth sector is the last transitional movement (also preparation phase) and precedes the downstroke by pressing forward over the top from about 320 to 20 degrees.
Figure 1 illustrates the four sectors of the pedal stroke cycle and the muscles activity.

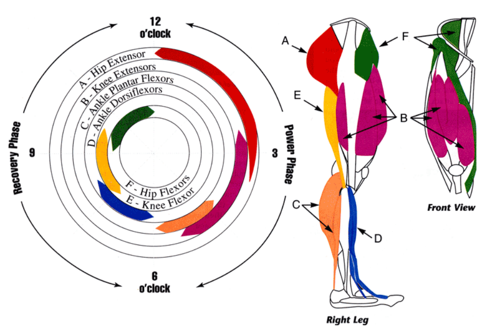

Figure 1: The four sectors during the pedal stroke cycle and the activity of the involved muscles during each sector.

Elite cyclists apply force using the correct leg muscles with optimum physiological effort. In contrast, novice cyclists push the vast majority of the force down as the pedal goes down instead of pulling the foot back and around in a circle. A common ‘mistake’ in the movement is a pause in the stroke after the push-down phase and before the start of pulling-back and up.

1.2. Feedback training in cycling

To control the cyclists pedaling technique, biomechanical feedback can be used, commonly by visualizing how the force is applied in the pedal stroke on a display. Research found, that augmented biomechanical feedback of pedal forces supports the development of a new pedaling pattern and can improve pedal force effectiveness within a training session and after multiple sessions for trained cyclists [7] and recreational cyclists [8] at aerobic power output. The results showed that cyclists could change their technique by actively pulling up during the recovery phase. However, doing so impaired their mechanical efficiency [5]. Only Mornieux and Stapelfeldt [9] have tested effects of longer training using visual force feedback.

A major drawback of visual information perception is that it is attention-consuming to concentrate on keeping the eyes permanently focused on the display. In contrast, acoustic information offers the advantage of parallel perceiving several sensory stimuli without perceptual overload [10] and is beneficial for timing in motor skills because it can improve temporal precision and reduce variability [11]. To date the only acoustic feedback was provided for cadence control via an audio metronome [12].

Because of its cyclic nature, the pedal stroke is well suited for an acoustic mapping. Sonification of the forces applied on the pedal throughout the cycle can draw the cyclists’ attention to asymmetries in pedal forces throughout the cycle as well as on leg differences. This paper aims at describing an application of interactive sonification to create coherence between action and reaction for the forces applied on the pedals during the cycling motion on an ergometer in addition to visual feedback. The sonification was pilot-tested with recreational cyclists to assess their impression.

2. METHODS

Cycling ergometers allow for measuring a constant workload in laboratory controlled conditions and provide an ideal experimental situation.

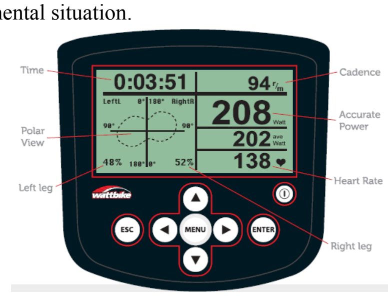

Figure 2: The Wattbike console with polar graph of pedal stroke.

2.1. Measuring system – The Wattbike cycle ergometer

The air-braked Wattbike cycle ergometer (Wattbike Ltd, Nottingham, UK) calculates power output by measuring the chain tension over a load cell (sampled at 100 Hz) and the angular velocity of the crank arms (twice per revolution). The data is updated in a display either on the bike console (Figure 2) or transferred via USB to a PC and displayed in the Wattbike Expert Software. The Wattbike samples data 100 times a second and is recording data for each pedal revolution. It also measures and, in the software, records 39 different cycling parameters.

Typical of most standard bike monitors cadence is displayed in rotations per minute as well as distance, time and other factors such as heart rate. The Wattbike also displays power output, both in terms of average power during that pedal stroke as well as a Polar view of the wattage over the course of the most recent pedal stroke. The data including the polar graph of the output is updated once per pedal revolution. The Wattbike also indicates left and right leg symmetry, although it is worth noting that the Wattbike attributes all generated wattage to the pedal that is currently in the down or ‘power’ phase of the stroke, i.e., pulling up on the pedals versus pushing down on the pedals is not differentiated. The Wattbike provides accuracy on par with other top cycling ergometers [13].

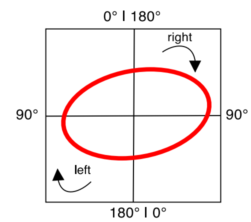

Figure 3: The Wattbike Polar View displayed in the perspective of the right pedal. The simulated red line is the wattage during each instance of the pedal stroke through a full revolution. The left pedal stroke is 180 degrees out of sync.

Wattbike suggests a few key measures to be used to assess your pedaling technique:

• Left and right leg symmetry (50%/50% balance)

• Left and right leg angle to peak force (the same angle for each leg) – when using Wattbike Expert software

• Overall shape of the Polar graph

Wattbike’s research indicates that cyclists who have refined their pedaling technique report the ability to produce more power and higher cadence for the same physiological effort. Wattbike outlines three progressions through pedal stroke efficiency, beginner, good and elite as illustrated in Figure 4.

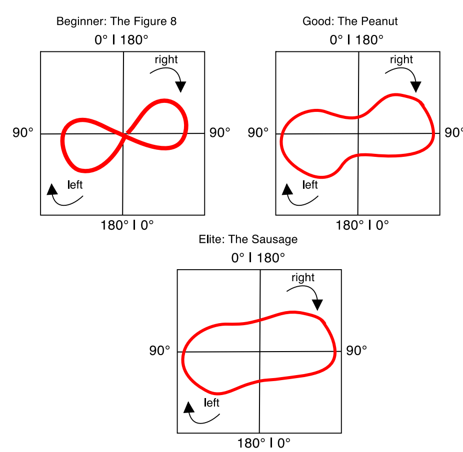

Figure 4: The progression of cycling pedal stroke efficiency.

2.2. Sonifying the Wattbike

While the Wattbike tracks many different cycling stroke metrics, the most interesting is the real-time wattage used to produce the polar graph of the pedal stroke. Herman et al. [14] proposed that sonifying the intermediate effects of actions, especially those produced from repeating actions, allows a user to systematically relate to sound changes and make revisions over a number of repetitions. In each of the cycling pedal stroke progressions outlined in Figure 4, the data takes on a cyclic characteristic. Schaffert et al. [15] sonified the acceleration time trace of a rowing boat, which enhances the users' ability to perceive the slowing down of the boat during the glide phase of the movement. Godbout et al. [16] synchronized various running models against incoming acceleration data from the running movement allowing the sonification to differ based on which classification of running movement was being detected a situation similar to the pedal stroke classification.

Wattbike provides an application programming interface (API) allowing developers to access summary information about a single cycling stride. Examples of the summary information that developers may access once per pedal revolution include:

- Cadence, Distance, Speed, Heart rate
- Left and right percent of power generated
- Left and right time to force peak

Unfortunately, Wattbike does not provide access to the real-time wattage information that is used to create the polar graph. It is onerous but possible to access this information by comparing raw bytes of data leaving the Wattbike against processed data in the Wattbike Expert software. Figure 5 shows how manual pattern matching helped determine that the data used to form the polar graph (blue) is formed from the raw data exiting the Wattbike (green).

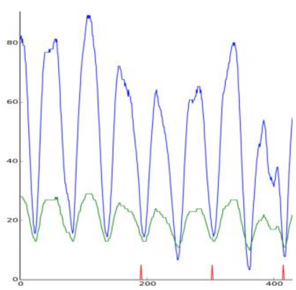

Figure 5: Post hoc comparison of raw data (green and red) versus Watt Bike wattage. The blue data (exported post hoc from the Wattbike Expert Software) is determined as being generated from the raw green data.

2.3. Sonification Methods

In this preliminary assessment of sonifying the Wattbike data, we provide a number of sonification methods. The first sonification option is parameter mapping the incoming wattage values from the Wattbike to pitch. This is a standard sonification, the rhythmic nature of the wattage from the pedal strokes produces rhythmic changes to the pitch of a sinetone. The pitch is normalized to fall between 200 Hz and 400 Hz. We experiment with parameter mapping watts to other sound characteristics such as the playback speed of a song and a combination of pitch and duration between short ticks. Ultimately, we decide the parameter mapping between watts and pitch produces output that can be easily interpreted. We test the parameter mapping from wattage to pitch as outlined below.

As a basis for further sonifications we first build a model set of pedal strokes. We then sychronize the incoming wattage with each of the model strokes. While we follow the same process as in Godbout et al. [16] we have an advantage in that the Wattbike allows us to determine each time a new pedal stroke begins. This solves the problem of left/right differentiation which was previously not possible due to the symmetry in the data. This also optimizes the correlation because we can normalize the lengths of each of the model pedal stroke and incoming pedal stroke.

A successful sychronization will produce two outputs: 1) the pedal stroke model that the user is most closely matching (Figure 8, Peanut or Sausage) and 2) the phase of the pedal stroke. Now we build a sonification that is driven by the phase output from our synchronization. When the phase ramp crosses certain thresholds we then parameter map the wattage to sound output just as before. Depending on how closely we place the thresholds the sound takes on a less continuous nature.

Because the elite cyclist produces a sausage shape, the parameter mapping of wattage to pitch starts to mimic a continuous unchanging sinetone and while it is easy for a cyclist to hear the rhythmic nature of the beginner.

3. TESTING

Pilot tests were undertaken with four recreational cyclists (two males and two females, 35.3±0.9 years old) with experiences in cycling to prove the applicability/usefulness of the sonification. Tests were executed in laboratory-controlled trials at aerobic level of workload (submaximal cycling) to avoid influences of fatigue and to keep the participant's attention on executing a correct pedaling technique. They were instructed to concentrate on eliminating dead spots throughout the pedal stroke and were told to focus on two key points: (1) at the bottom of the pedal stroke, they should imagine of wiping something off their shoe to engage the muscles on the back of the leg, (2) at the top of the pedal stroke, they should think about pushing their knee toward the handlebar to get the power on early.

The sonification was provided via earplugs during cycling and the participants' impression of the sound as well as the idea of providing acoustic feedback during cycling was requested in free response. The questions addressed the sound's comprehensibility, its correspondence with the pedal stroke cycle and forces applied, as well as the sounds attention-guidance effectiveness for specific sections throughout the cycle.

The results of the request revealed that the sonification audibly represents the forces applied on the pedals throughout the stroke cycle. Changes in tone pitch were perceived particularly during the downstroke sector, where the pedal goes down and most of the force was applied. Also the lowering of the sound after the push-down phase and before the start of pulling-back and up was mentioned. The sound provided an imagination of 'mistakes' in movement execution. Participants reported a more sensitized self-awareness for their pedaling technique. The sound provided a stable reference for the cycling movement and was perceived as functional and supportive. Consequently, they became aware of the characteristics in the pedal stroke cycle. Comments included the following: “I noticed details of which I wasn’t aware before.” …“The feeling for the pulling-back and up during the recovery phase is improved.” … “It is easier to actively pull on the pedal when performing with the sound.” The question “did sonification help to work on leg symmetry?” was totally agreed from all participants. “It is instantly noticeable if the forces between the legs were different.” The results indicated that further investigations into the sonification of pedal stoke to be a valuable procedure. The Wattbike has a couple of nice features - it already has visual output allowing for 1) interesting tests concerning validation and comparison between visual and auditory feedback, 2) Wattbike has already outlined a purpose for its output (namely the corrections in cycling stride).

4. DISCUSSION AND CONCLUSIONS

The paper introduces a system for sonifying data from a Wattbike cycling ergometer. The goal is to provide acoustic feedback during cycling to make cyclists aware of their pedaling technique and to keep them concentrated on its correct execution. By an acoustic presentation of the force applied throughout the pedal stroke cycle, the information contained in the captured-data is provided directly and intuitively to the cyclist. Periodic recurrence of characteristic sections within the stroke cycle represents the rhythm of the pedal cycle and can sensitize for details in the sequence without further explanations needed. Sound can help to alter the pedal stroke by providing an instant auditory representation of the forces applied on the pedals, which give support to maintain the smoothness and fluidity of the pedaling motion during the training session.

The results of the request were motivating and lead to the conclusion, that the sonification can be regarded as a helpful training tool. However, since no research has been conducted to quantify the relationship between symmetry in pedal forces and performance [3], further studies are needed to elucidate this relationship.

The noises made by the Wattbike itself (due to its air-brake system) could have been a limiting factor for providing real-time acoustic feedback as they could mask the sonification. Since the participants have not mentioned them as disturbing or interfering with the sound, it seems not to be a problem for further investigations. Possibly because the sonification was provided via earplugs, which partly mask the surrounding sounds.

Working with the Wattbike itself presented a challenge as the differences in minimum time-delay required for effective visual versus effective auditory feedback differ significantly. The Wattbike as designed only provides easy access to once-per-pedal stroke summary information. Gaining access to the real-time information was a significant undertaking. After gaining this access the Wattbike provides a nice tool moving forward to assess the effectiveness of acoustic feedback and comparing against visual feedback.

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